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MAGNETIC AND ELECTRONIC BALLAST

Life cycle assessment of magnetic and electronic ballast for 36-W fluorescent lamp

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Abstract
Background, aim, and scope Ballast is a device in a fluorescent lamp that supports the production of light. In this study, the environmental impacts of two types of Malaysian ballast, magnetic ballast and electronic ballast, were identified and compared using the life cycle assessment approach through the ISO 14040 (2005) series.
Materials and methods The functional unit is consumption of 36 W ballast for a fluorescent lamp of 36 W during 10 years of working hours. The life cycle impact assessment was determined by the Eco-indicator 99 method. Only material processing, production, and use stages were considered in this study. Component inventory showed steel to be the major component in both the magnetic and electronic ballasts, used as the core steel and housing, respectively.
Results, discussion, and conclusions For raw material and manufacturing phases, electronic ballast registered higher value for each damage category: 2.92×10^{-5} disability adjusted life years (DALY) for human health, 1.43 potential disappeared fraction of plants (PDF)m^2year for ecosystem quality and 17.02 MJ surplus for resource depletion compared to those for magnetic ballast at 4.08×10^{-6} DALY, 0.83 PDFm^2year, and 3.53 MJ surplus, for their respective damage categories. For the use phase, magnetic ballast used more energy (135 kWh) than electronic ballast (45 kWh) and also registered more impact during the use phase with 3.57×10^{-5} DALY for human health, 3.25 PDFm^2year for ecosystem quality, and 219.43 MJ surplus for resource depletion, compared to electronic ballast's 1.19×10^{-5} DALY, 1.08 PDFm^2year, and 73.14 MJ surplus for their respective damage categories.

Keywords Eco-indicator 99 · Electronic ballast · Fluorescent lamp · Life cycle assessment (LCA) · Magnetic ballast

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1 Introduction

Lighting systems take up about 30% of energy consumption of a commercial building (Li et al. 2006). Of the many types of lamps such as incandescent, fluorescent, high-intensity discharge and low-pressure sodium lamps (Gordon 2003), fluorescent lighting is the most popular because it is similar to natural daylight (Sherwin 1999). To function, a fluorescent lamp requires ballast which operates as a current limiting device and provides the right voltage to start off the lamp. Ballasts are very specific for the particular lamps since ballast controls the wattage of a lamp. If an 18-W T8 fluorescent lamp uses 36 W ballast, the lamp will operate at 36 W, which will cause lower lamp performance and premature ballast failure (Gordon 2003). There are two types of ballast, magnetic and electronic ballast (Simpson 2003). Magnetic ballast starts and regulates a lamp through a core-and-coil assembly. This assembly consists of two copper wires coiled around a common core of steel laminations to transfer electrical current from the power supply into the appropriate wattage as required by the lamp. Once in operation, the ballast will maintain the electrical flow along the lamp-ballast circuit to keep the fluorescent lamp alight. However, magnetic ballast

generally produces disturbance such as noise and flicker (Gordon 2003). The noise results from the vibration of the steel laminations in the core-and-coil assembly. Flicker arises from an insufficiency of lamp efficacy (the lamp's ability to convert electrical energy to light energy) due to the low-frequency operation of magnetic ballast (Simpson 2003).

Electronic ballast is similar in function to magnetic ballast except that it uses entirely electronic components to start and regulate the lamp. The use of electronic technology causes this electronic ballast to work at higher efficiency and frequency and so eliminates the noise and flicker (Simpson 2003). Electronic ballasts are also typically lighter in weight than their magnetic counterparts as the core-and-coil assembly in magnetic ballast is made of metals and is therefore heavier. However, electronic ballast is susceptible to electrical and electronics disturbances and is more expensive (Zhou 2003). In Malaysia, the cost of an electronic ballast is about seven to eight times higher than a magnetic ballast for the same type of lamp.

Life cycle assessment (LCA) is a tool for the systematic evaluation of the environmental aspects associated with a product over its life cycle (Udo de Haes and Heijungs 2007). The life cycle stages of a product include raw material acquisition, material processing, production, assembly, transportation, use, and final disposal (Labuschagne and Brent 2005). Environmental evaluation using LCA is done in four steps: defining the goal and scope of the study, establishing a life cycle inventory, performing a life cycle impact assessment (LCIA), and finally interpreting the environmental burden associated with the product (Asif et al. 2007; Dodbiba et al. 2008; Hospido et al. 2006; Peregrina et al. 2006).

In this study, the environmental impacts of magnetic and electronic ballast used in 36-W fluorescent lamps were identified and compared. Using Eco-indicator 99, impacts were for carcinogens, respiratory organics and inorganics, climate change, radiation, ozone layer, acidification, land use, ecotoxicity, minerals, and fossil fuels. These impacts are categorized into three damage categories: human health, ecosystem quality, and resource depletion (Goedkoop et al. 2007).

2 Data collection

Data from the Energy Commission of Malaysia shows a total of 47 registered ballast manufacturers in Malaysia from 1992 until 2008. Of these, 36 manufacture magnetic ballast only, three manufacture electronic ballast only, and 11 manufacture both types of ballast. Questionnaires and letters of permission were sent to all manufacturers, but only two replied and gave consent. Fortunately, these represented one manufacturer of magnetic ballast and one of electronic ballast. Site visits were made to these factories in Selangor and Penang for magnetic and electronic ballast, respectively.

3 Goal and scope definition

3.1 The goals of the study are:

a. Inventory the components of magnetic and electronic ballast for fluorescent lamp
b. Obtain energy use data for fluorescent lamp ballast
c. Evaluate and compare environmental performance for magnetic and electronic ballast using Eco-indicator 99

3.2 Scope of the study

3.2.1 System, function of the systems, and functional unit

The system under study is the ballast, not including the lamp. The ballast is a unit of 36 W magnetic and electronic ballast operating with a 36-W T8 (1-in diameter, tube shaped) fluorescent lamp (Fig. 1). The ballast functions by limiting the electrical current flow through the lamp and providing the right voltage to the lamp to start off. The functional unit is the use of a ballast of 36 W for a T8 (1-in diameter, tube shape) fluorescent lamp of 36 W during continuous working hours for 10 years.

3.2.2 System boundary

The system focuses on the 36 W ballast (see Fig. 1) used in a fluorescent lamp of 36 W. The production of, replacement of, and any process related to the fluorescent lamp and starter are not considered in this system. The boundary of the system is limited to the production and use stages of the lifetime of the ballast. The transportation and end-of-life stages, although very important for any impact assessment, have to be excluded from the study due to serious lack of data. The lifetime chosen for the ballast to function (use stage) is 10 years, based on the minimum operating capacity of electronic ballast of 30,000 h, which is equivalent to 10 years of continuous 9-h operation a day.

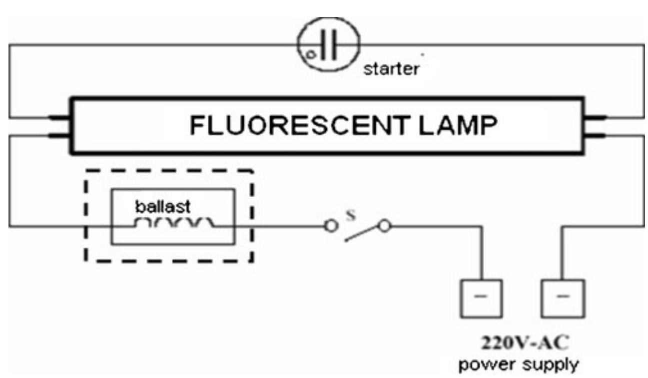

Fig. 1 The system focuses on the 36 W ballast used in a fluorescent lamp of 36 W

Magnetic ballast has no specific lifetime and is long-lasting, but electronic ballast can operate from 30,000 h (minimum expectancy) up to 50,000 h (maximum expectancy). Therefore, 10 years fulfill the 30,000 h of operation for total consumption during continuous working hours a day (9 h).

4 Life cycle inventory

4.1 Component inventory

Table 1 and 2 show components of magnetic and electronic ballasts, respectively. In magnetic ballast, the most important source is steel, making up a total of 85.9%. Copper, used as wire winding, is next at 10.4%. The others, nylon bobbin, polyester film, aluminum, paint, thinner, and paper make up a much smaller component of the ballast in a range of 0.1–1.5% of the total weight. In the electronic ballast, steel contributes 49.8% of the mass in the form of the casing. The other 45.8% is attributed to the electronic components, which include transformer (20.7%), capacitor (9.3%), printed circuit board (PCB; 8.2%), resistor (1.7%), transistor (1.6%), diode (1.3%), jumper wire (0.8%), negative temperature coefficient (0.7%), integrated circuit (IC's) (0.6%), inductor (0.5%), and potentiometer (0.5%). Other smaller components in electronic ballast are nylon (1.5%), solder paste (1.3%), fuse (0.8%), and copper (0.7%). A comparison of component inventories of magnetic and electronic ballast is shown in Table 3.

4.2 Energy inventory

4.2.1 Data from manufacturing process (ballast assembly)

Electricity is the only source of input during assembly.

For magnetic ballast:

a. Total electricity used per month—4,333.33 kWh
b. Total production a day—8,000 pieces

Table 1 Components of magnetic ballast

No.	Component	Weight (g)	Mass (%)
1	Steel	850	85.9%
2	Copper wire	103	10.4%
3	Nylon Bobbin	15	1.5%
4	Polyester film	10	1.0%
5	Aluminum	5	0.5%
6	Paint	2	0.2%
7	Thinner	1	0.1%
8	Paper	1	0.1%
9	**Total**	**990**	**100.0%**

Table 2 Components of electronic ballast

No.	Component	Weight (g)	Mass (%)
1	Steel	177.8	49.8%
2	Transformer	73.8	20.7%
3	Capacitor	33.2	9.3%
4	PCB	29.3	8.2%
5	Insulation material	10.5	2.9%
6	Resistor	6.0	1.7%
7	Transistor	5.6	1.6%
8	Nylon bobbin	5.4	1.5%
9	Solder paste	4.8	1.3%
10	Diode	4.6	1.3%
11	Fuse	1.6	0.4%
12	Jumper wire	1.4	0.4%
13	NTC	1.0	0.3%
14	Wire	1.0	0.3%
15	IC's	0.5	0.1%
16	Fixed inductor	0.2	0.1%
17	Potential meter	0.3	0.1%
18	**TOTAL**	**357**	**100.0%**

NTC negative temperature coefficient

c. Total production a month—160,000 pieces
d. Electricity consumption to manufacture (assemble) one magnetic ballast is:

$$4{,}333.33\ \text{kWh}/160{,}000\ \text{pieces} = 0.03\ \text{kWh}$$

For electronic ballast:

a. Total electricity used per month—4,000 kWh
b. Total production a day—300 pieces
c. Total production a month—6,000 pieces
d. Electricity consumption to manufacture (assemble) one magnetic ballast is:

$$4{,}000\ \text{kWh}/6{,}000\ \text{pieces} = 0.67\ \text{kWh}$$

For production of one unit, electronic ballast requires more energy (0.67 kWh) than magnetic ballast (0.03 kWh). This difference is likely due to the electronic ballast's more complex components and use of a printed circuit board, which results in more complex processing and thus requires more energy.

4.2.2 Data from the use phase

The magnetic and electronic ballasts each operate in a T8 fluorescent lamp. During the use stage, magnetic ballast requires 6 W of electricity and electronic ballast uses only 2 W. During a use scenario (to keep a fluorescent lamp alight), calculation will be based on usage for nine continuous hours a day (working hours). Under this

Table 3 Comparison of component inventories of magnetic and electronic ballast

No.	Subject	Magnetic ballast	Electronic ballast
1	Main component	a. steel (electrical laminations)	a. steel (casing)
		b. copper (wire winding)	b. electronic components
2	Quantity of component	8	17
3	Weight (g)	990	357

scenario, magnetic ballast uses 0.054 kWh a day (0.006 W×9 h) and electronic ballast uses 0.018 kWh a day (0.002 W×9 h). Thus, for 10 years of lifetime, the ballast is used for:

a. One time a day (for 9 h; 1×1=1 times/day)
b. Five times a week (1×5=5 times/week)
c. For 50 weeks a year (5×50=250 times/year)
d. For about 10 years (250×10=2,500 times)

That is, the total usage is 2,500 times over 10 years of the lifetime of the product. Total electricity consumed for both magnetic and electronic ballast is therefore calculated thus:

i. Magnetic ballast 135 kWh (0.054 kWh×2,500)
ii. Electronic ballast 45 kWh (0.018 kWh×2,500)

In summary, the energy inventory shows that electronic ballast requires more energy during the production stage but uses less energy over its expected lifetime (10 years) than does magnetic ballast. Magnetic ballast, on the other hand, consumes more energy (approximately 6 W) during the use phase than electronic ballast (2 W). Electronic ballast is able to conserve its energy consumption because the technology allows it to operate at a higher frequency, from 25 to 70 kHz (Zhou 2003) as compared to the normal rate of around 50 Hz. The magnetic ballast is only able to operate around normal rate of between 50 and 60 Hz. The capacity of electronic ballast to operate at the higher frequency increases ballast and lamp performance, hence, increases its energy efficiency (Simpson 2003).

5 LCIA

The Eco-indicator 99 method was used to analyze the potential environmental impact using Simapro 7.1 software. Under the Eco-indicator 99 method, impacts were classified into carcinogens, respiratory organics and inorganics, climate change, radiation, ozone layer, acidification, land use, ecotoxicity, minerals, and fossil fuels (Goedkoop et al. 2007). These impacts can be grouped into three damage categories: human health (carcinogens, respiratory organics and inorganics, climate change, radiation, and ozone layer), ecosystem quality (acidification, land use, and ecotoxicity), and resource depletion (minerals and fossil fuels). Human health impacts were assessed using disability adjusted life years (DALY) unit, while potential disappeared fraction of plants (PDF) m^2year was used to assess ecosystem quality impacts and MJ surplus energy for resources depletion impacts. Results of the LCIA analyses are presented according to these three damage categories.

5.1 LCIA for production phase

Comparison of impacts associated with the production stage show that electronic ballast contributes more than magnetic ballast does to all three impact categories. Electronic ballast showed 2.92×10^{-5} DALY for human health, 1.43 PDF m^2year for ecosystem quality, and 17.02 MJ surplus for resource depletion while magnetic ballast showed 4.08×10^{-6} DALY, 0.83 PDF m^2year, and 3.53 MJ surplus for each damage category, respectively. When each ballast is analyzed according to its components, the capacitor in electronic ballast gave higher impact on human health (1.77×10^{-5} DALY) and ecosystem quality (0.63 PDF m^2year), and PCB contributed most to resource depletion (3.13 MJ surplus). For magnetic ballast, copper for wire winding showed a higher impact value with 3.17×10^{-6} DALY, 0.70 PDF m^2year, and 2.89 MJ surplus for each damage category, respectively.

5.2 LCIA for use phase

Electricity is the only source used during the use phase. The impacts of electricity consumption for 10 years continuous working hours of 9 h per day showed that magnetic ballast contributed more to all impact categories than did electronic ballast. During the use stage, damage to human health by magnetic ballast rated at 3.57×10^{-5} DALY, for ecosystem quality 3.25 PDF m^2year, and for resource depletion 219.43 MJ surplus compared to electronic ballast's 1.19×10^{-5} DALY, 1.08 PDF m^2year, and 73.14 MJ surplus for the damage categories, respectively. Table 4 shows the total impact for the life cycle of both magnetic and electronic ballast. Overall, during the production and use stage, magnetic ballast contributed 3.98×10^{-5} DALY, 4.08 PDF m^2year, and 222.96 MJ surplus for human health, ecosystem quality, and resource depletion impact, respectively, compared to 4.11×10^{-5} DALY, 2.51 PDF m^2year, and 90.16 MJ surplus contributed by electronic ballast to the respective damage categories.

Table 4 Total impact for the life cycle (production, manufacturing, and use phase) of each ballast for each damage categories

Damage categories	Unit	Ballast	
		Magnetic	Electronic
Human health	DALY	3.98×10^{-5}	4.11×10^{-5}
Ecosystem quality	$\mathrm{PDF}\times\mathrm{m}^2\mathrm{year}$	4.08	2.52
Resource depletion	MJ surplus	222.96	90.16

The results from this study concur with other reported work on ballast by Hermann and Gallon (2005) and Soraluck (2008), who used the EDIP 2003 and EuP_EcoReport_V5 methods, respectively. Both compared magnetic and electronic ballast for fluorescent lamp over the whole life cycle. Both studies showed that electronic ballast consumed more energy and contributed higher impact values during the manufacturing phase, but was more energy efficient during the use phase, thus contributing lower impact value over its lifetime than did magnetic ballast. Their study also showed that the transportation phase exerted a non-significant impact due to the energy efficiency of the electronic ballast. Analysis of the end-of-life phase (Hermann and Gallon 2005) showed that magnetic ballast gave more environmental credit than did electronic ballast due to the recyclability of its steel and copper. However, their results were only significant if the use phase was not considered. Soraluck (2008) suggests further improvements to the existing electronic ballast through using less raw materials through reducing the ballast's size and weight, lowering the watt loss value, using more recyclable materials, using parts which are easy to disassemble (e.g., snap-in housing without screw), and using non-hazardous substances on all the parts.

6 Conclusions

Magnetic and electronic ballast were compared in this study taking a life cycle assessment approach. In the components inventory, steel was found to be a major component for both magnetic and electronic ballast, as housing materials, making up 85.9% and 49.8%, respectively. In the energy inventory, each unit of electronic ballast was found to require more energy during the manufacturing stage (0.67 kWh) than its magnetic counterpart (0.03 kWh). Magnetic ballast, however, consumes almost three times more energy than electronic ballast during the use phase. LCIA results of Eco-indicator 99 showed that during the production phase electronic ballast exerted higher levels of environmental impact that is associated with the damage to human health, ecosystem quality, and resource depletion, compared to magnetic ballast. Magnetic ballast, on the other hand, gave higher negative impact values during its use phase with 3.98×10^{-5} DALY for human health category, 4.08 $\mathrm{PDF\,m^2}$year, and 222.96 MJ surplus for ecosystem quality and resource depletion, respectively, compared to values of 4.11×10^{-5} DALY, 2.51 $\mathrm{PDF\,m^2}$year, and 90.16 MJ surplus for electronic ballast for each damage category, respectively.

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